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(54) Abstract Title
Stator pole/winding layout in a brushless motor

(57) A brushless DC motor includes a stator having a plurality of types of teeth 3,4 having different circumferential widths. The coils 13,14,15 of each phase are disposed so that the coil 13,14,15 wound on the wide tooth 3 is adjacent via the coil of another phase to the coil 13,14,15 wound on the narrow teeth 4. The coils 13,14,15 are wound on the teeth 3,4 repeatedly alternately in a sequence of the wide tooth 3 and the narrow tooth 4 or in a reverse sequence. Stator insulation comprises members 7,8 fitted to the stator, the rdially inner portions of which define inter-coil wiring guide channels eg 21 on the upper and lower surfaces (see also figs 11-14), terminal housings 29-34 being provided on the upper section. The insulation has protrusions 9d to locate the first layer of each coil. Auxiliary bindings eg 13b,c may be added. A winding arrangement is disclosed (fig17) and a three tooth system is described. The coil winding section of the teeth may be the same width, only the pole piece carried at the tooth tip being subject to the width requirement.

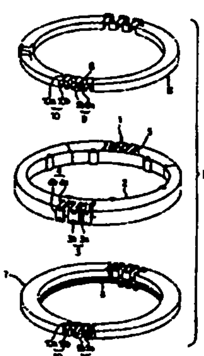
FIG. 2

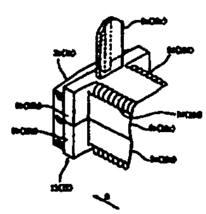
FIG. 3

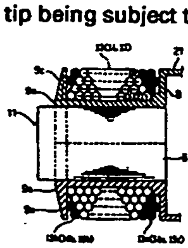
FIG. 6

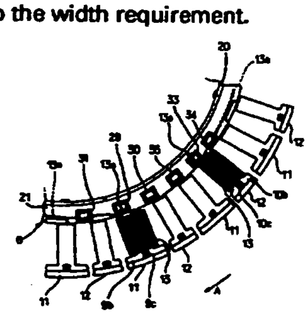
FIG. 7

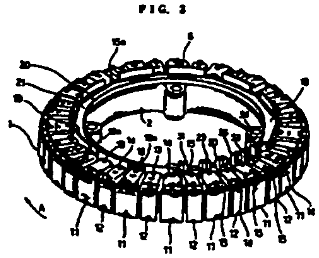
FIG. 4

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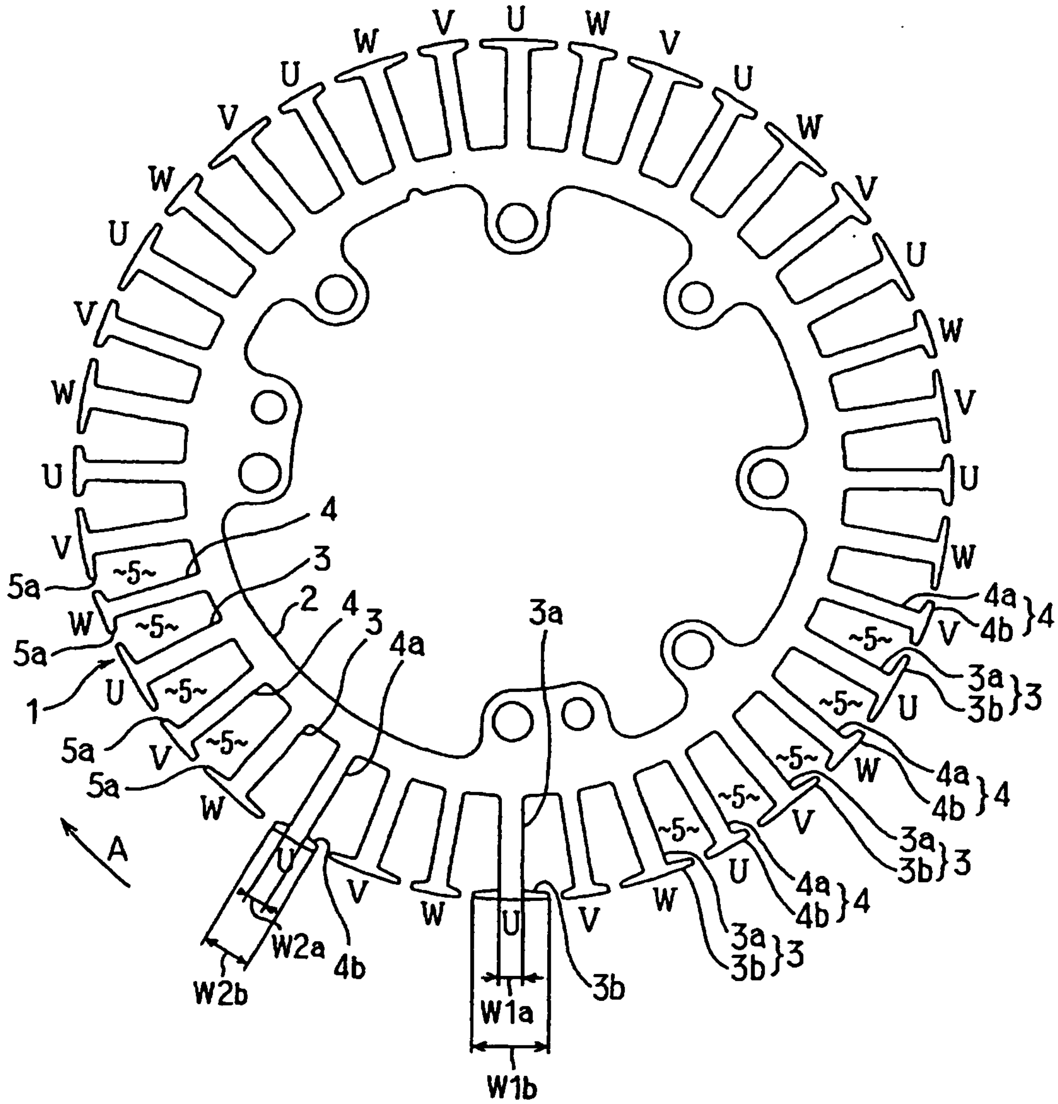

U
W
V
V
U
W
W
V
U
U
W
V
W
V
U
U
V
W
5a
~5~
4
3
W
~5~
5a
2
4
3
4a
3a
1
U
~5~
5a
V
~5~
5a
W
A
U
W2a
W2b
V
4b
W
U
W1a
W1b
3b
V
W
~5~
U
~5~
V
~5~
W
~5~
U
~5~
V
4a
4b
4
3a
3b
3
4a
4b
4
3a
3b
3
4a
4b
4
3a
3b
3

FIG. 1

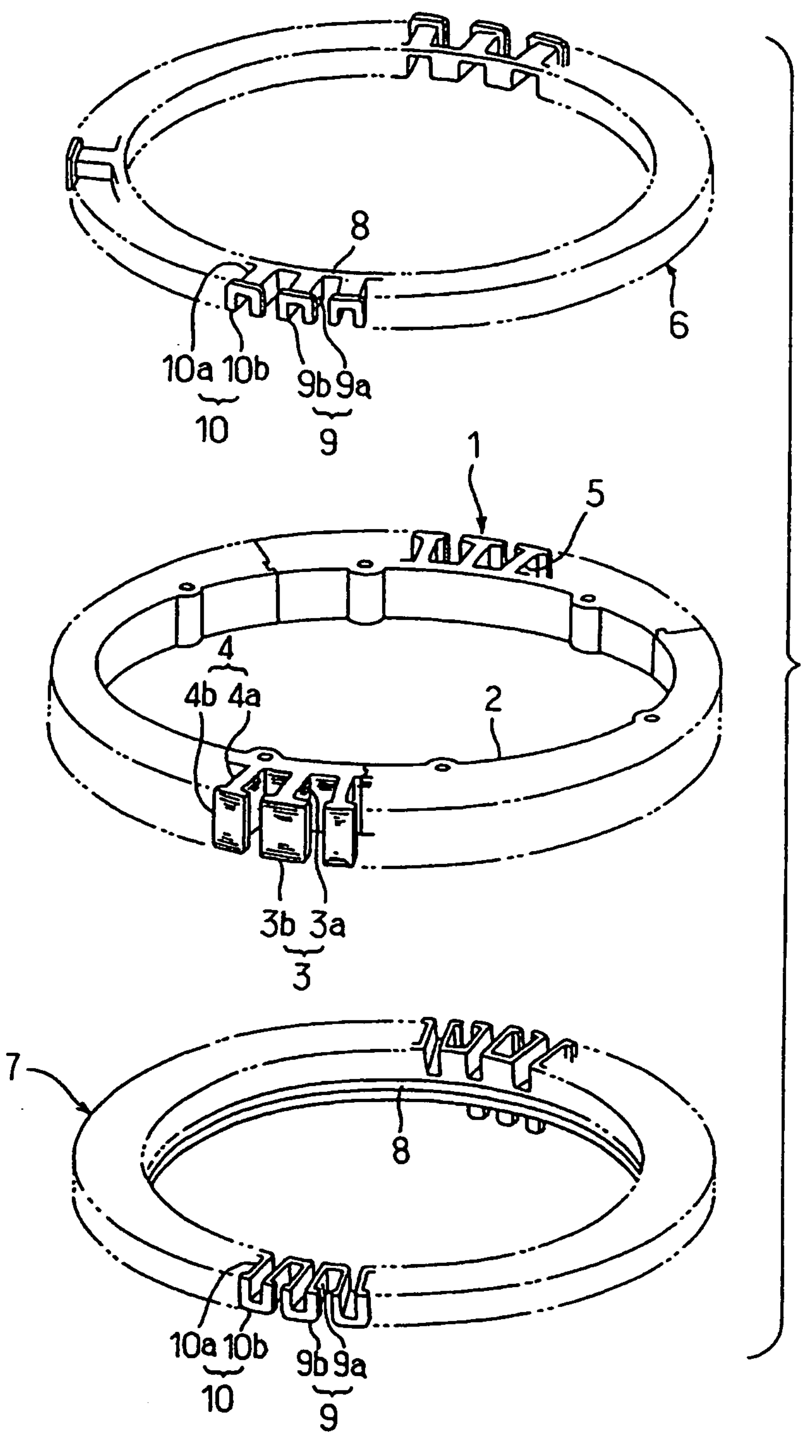
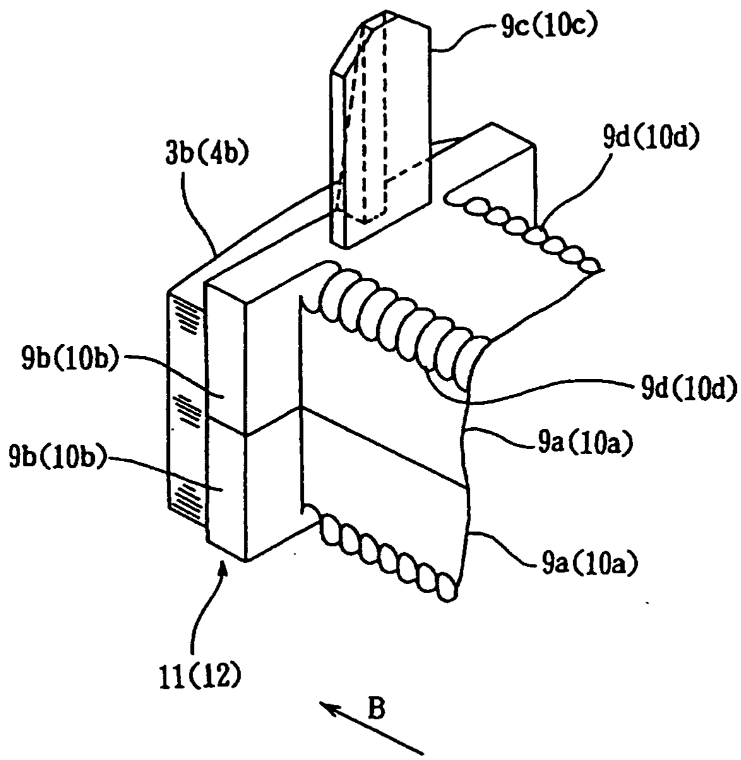


FIG. 2



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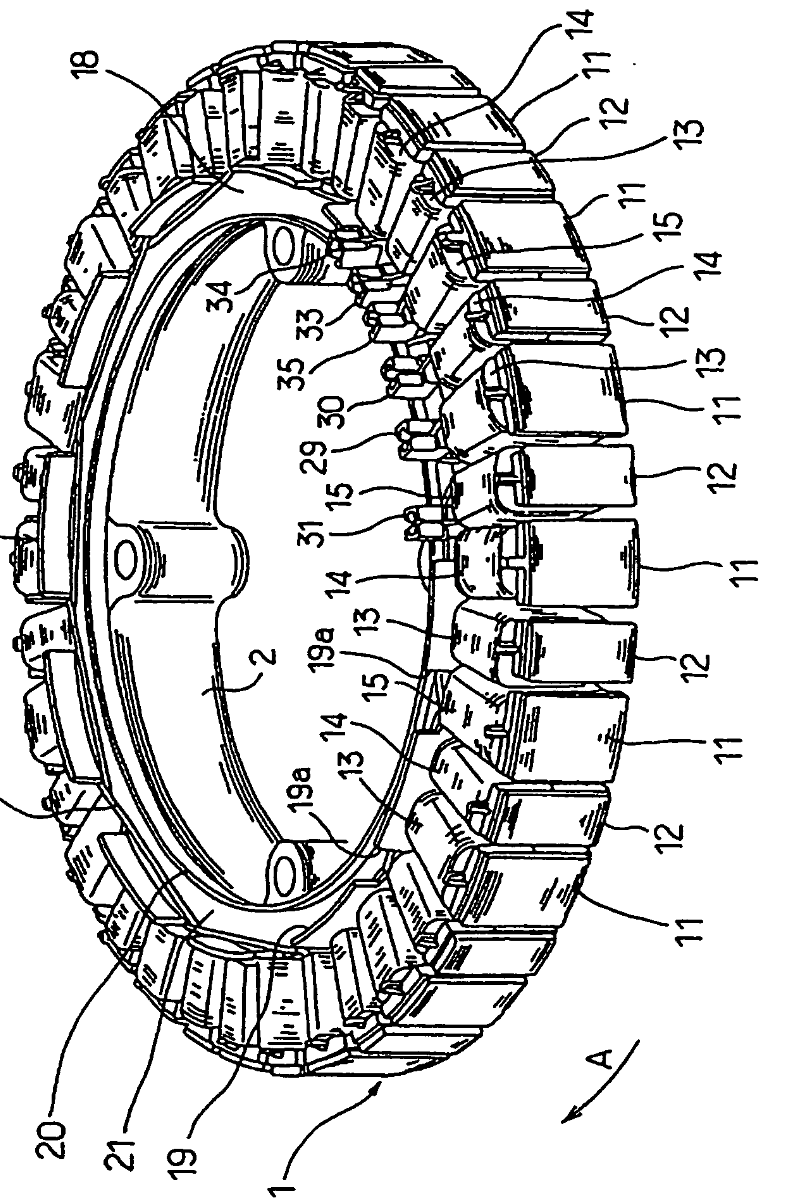

14
11
12
13
11
15
14
12
13
11
12
11
12
11
12
11
18
34
33
35
30
29
15
31
14
13
19a
15
14
13
19a
6
2
15a
20
21
19
1
A

FIG. 4

FIG. 5

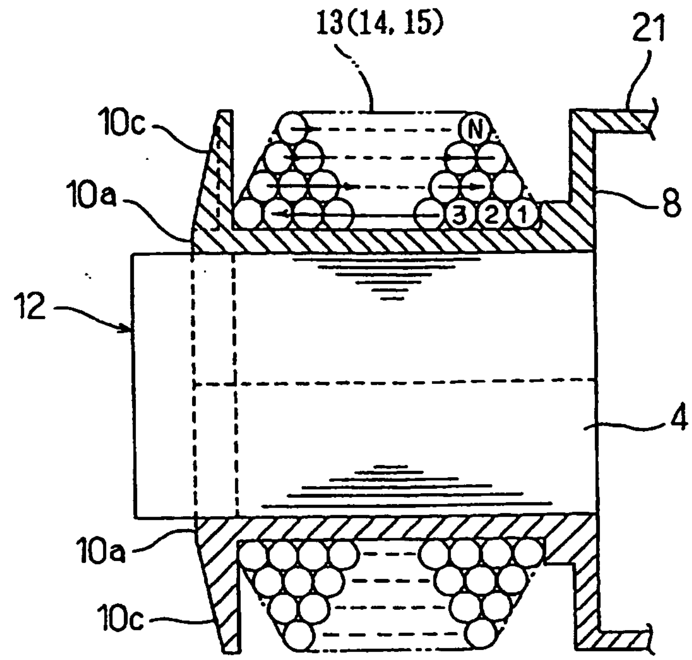
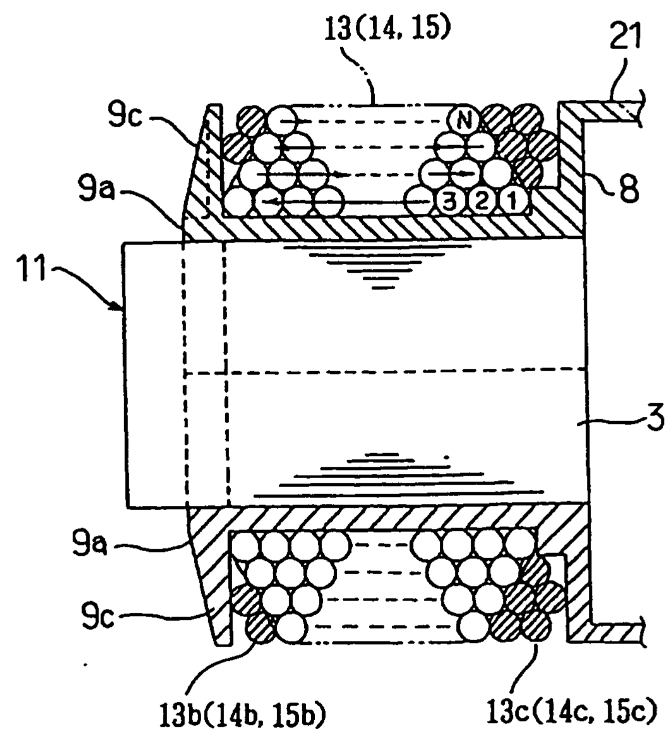

13(14, 15)
21
10c
10a
8
12
4
10a
10c

FIG. 6


13(14, 15)
21
9c
9a
8
11
3
9a
9c
13b(14b, 15b)
13c(14c, 15c)

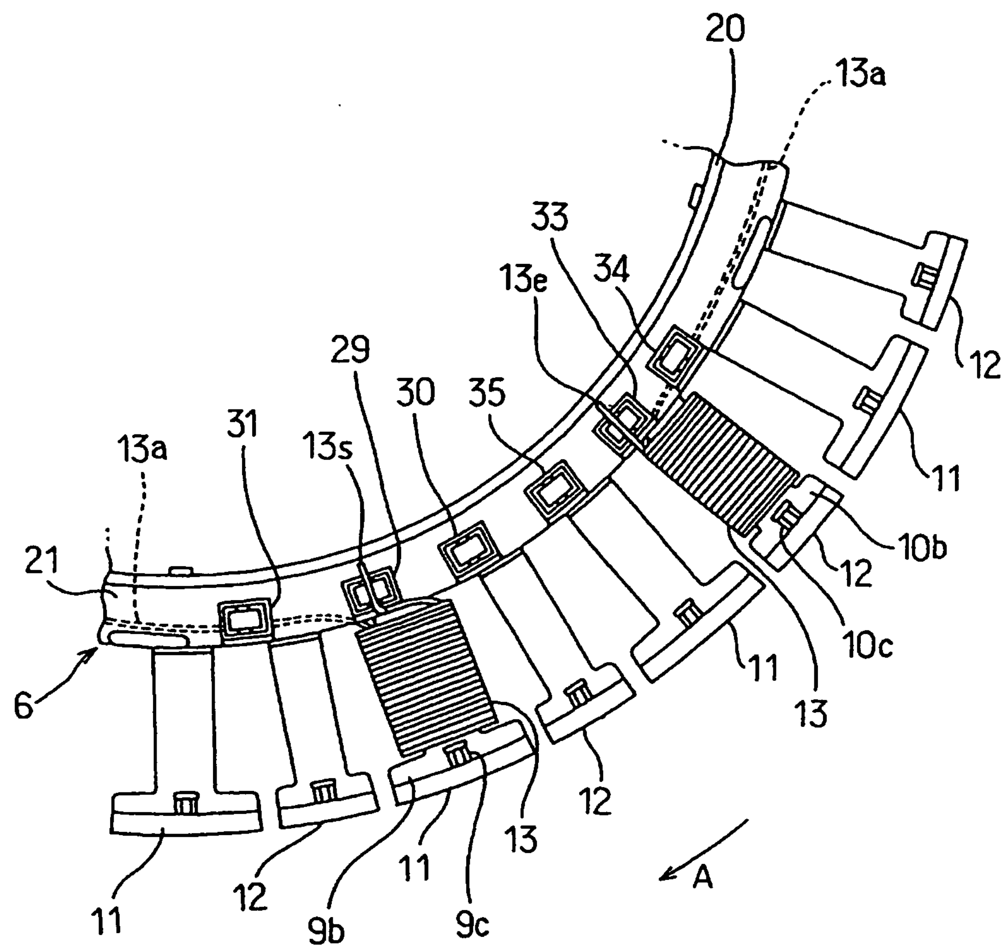

20
13a
33
34
13e
29
30
35
31
13a
13s
21
6
12
11
10b
12
10c
11
13
12
13
11
12
11
9b
9c
A

FIG. 7

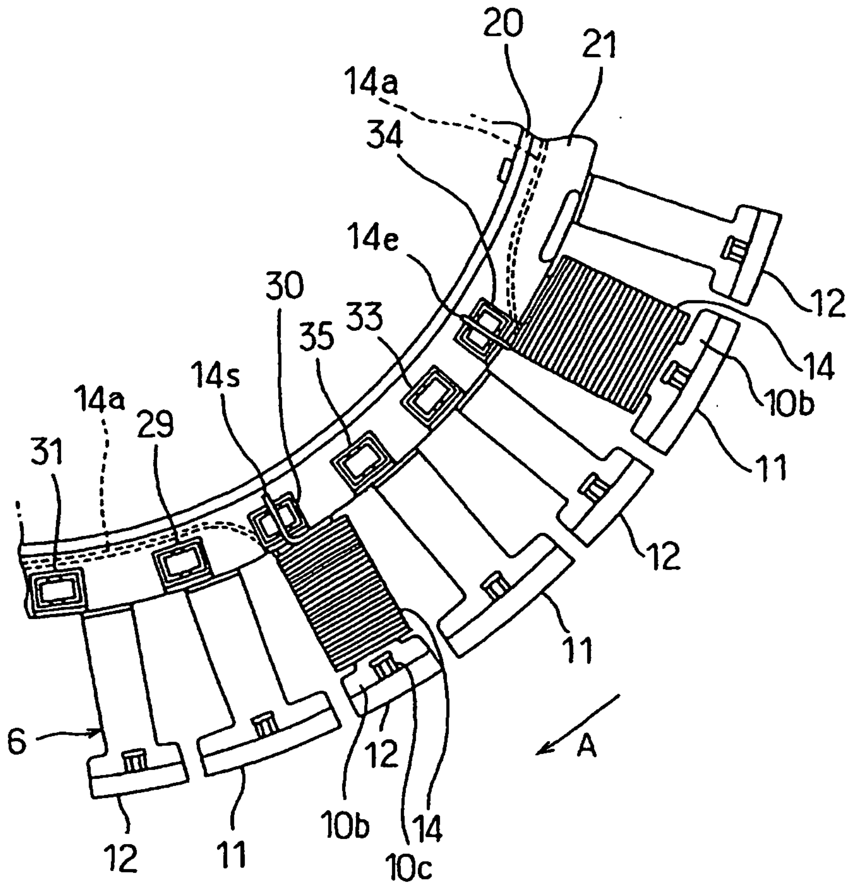

20
21
14a
34
14e
12
14
10b
11
30
33
35
14s
14a
29
31
12
11
6
A
12
10b
14
10c
12
11

FIG. 8

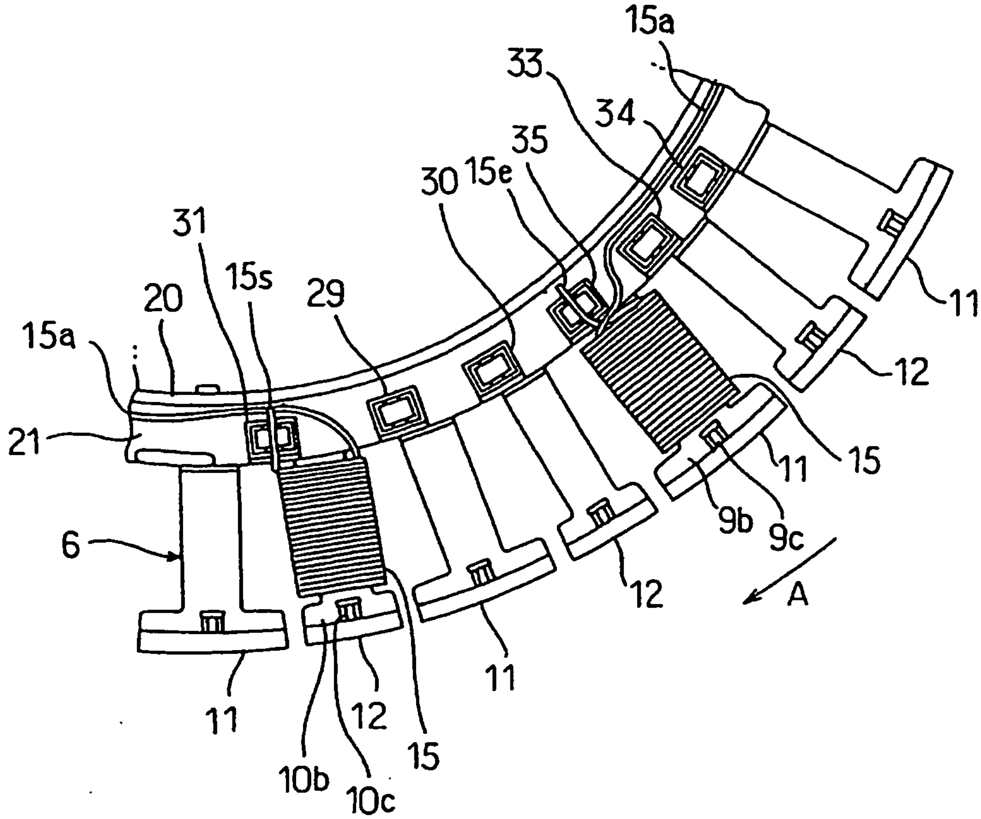
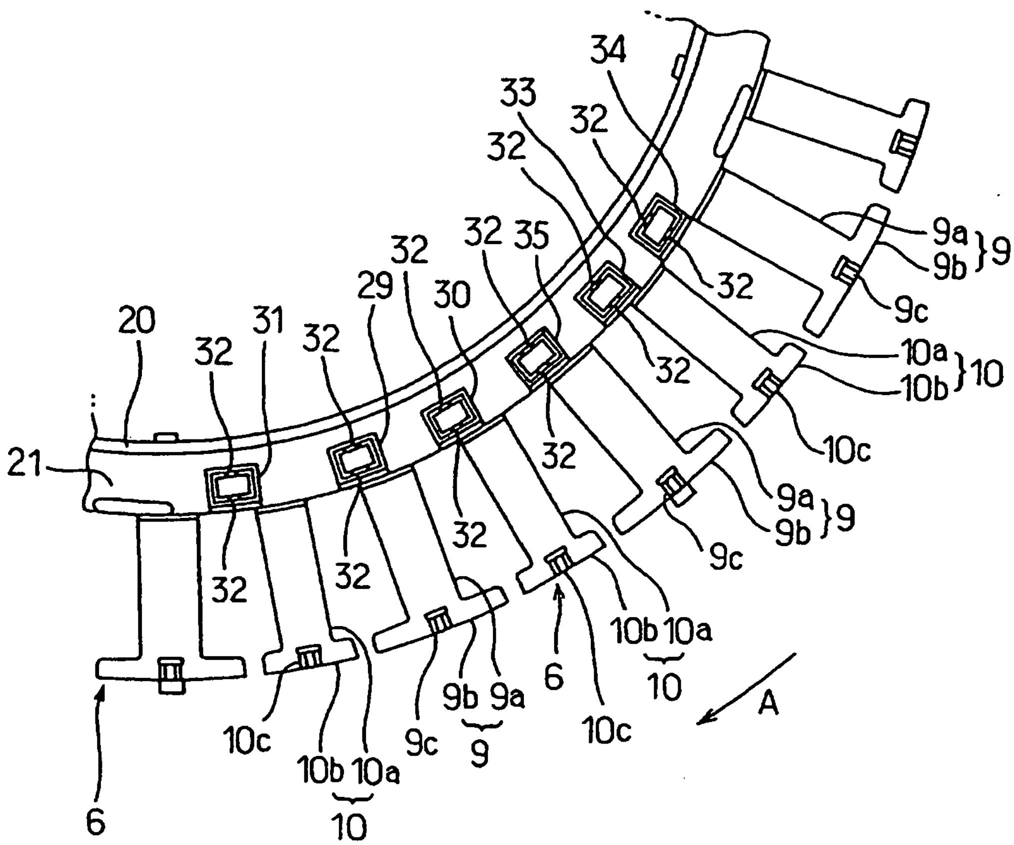

15a
33
34
35
30
15e
31
15s
29
20
15a
21
6
11
12
11
12
11
15
11
12
11
12
15
10b
10c
9b
9c
A

FIG. 9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31
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32
32
32
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32
32
9a
9b
9
9c
10a
10b
10
10c
9a
9b
9
9c
10b
10a
10
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10c
9c
9b
9a
9
10c
10b
10a
10
6
A

F I G. 1 0

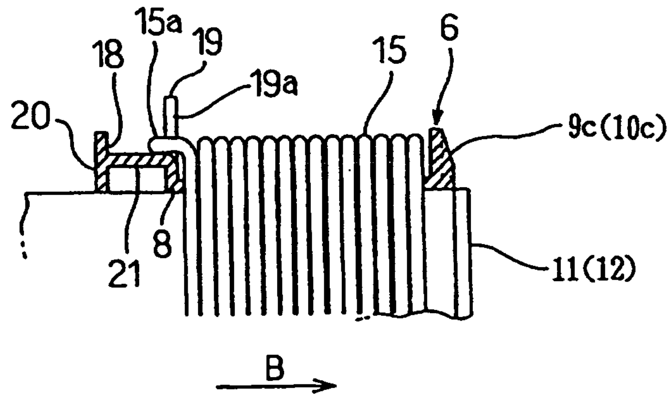

15a
19
18
19a
15
6
20
9c(10c)
21
8
11(12)
B

FIG. 11

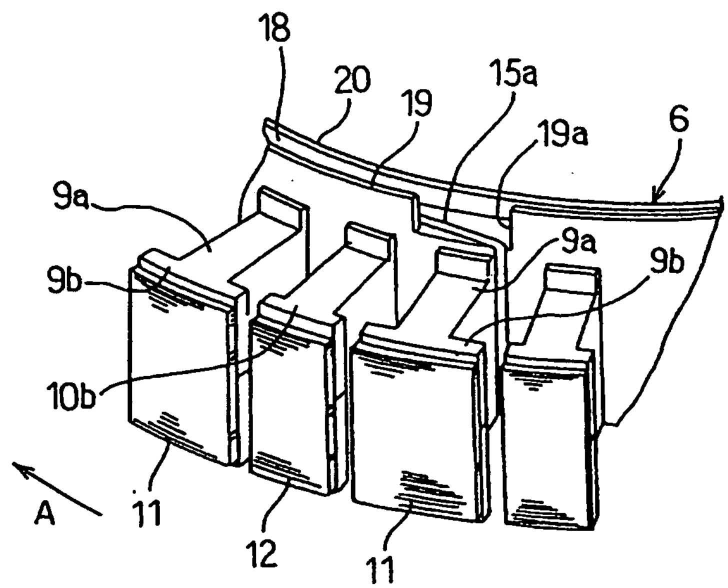
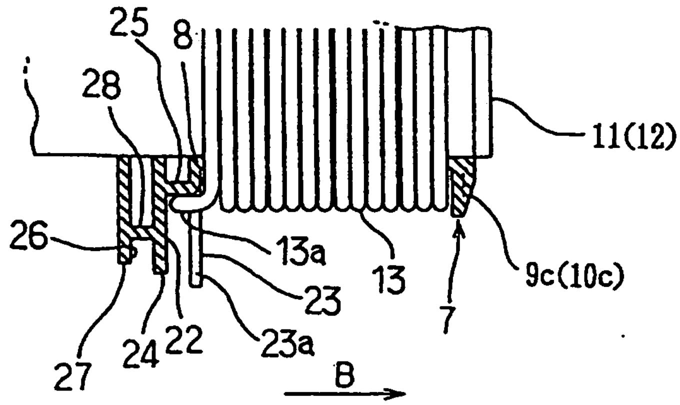
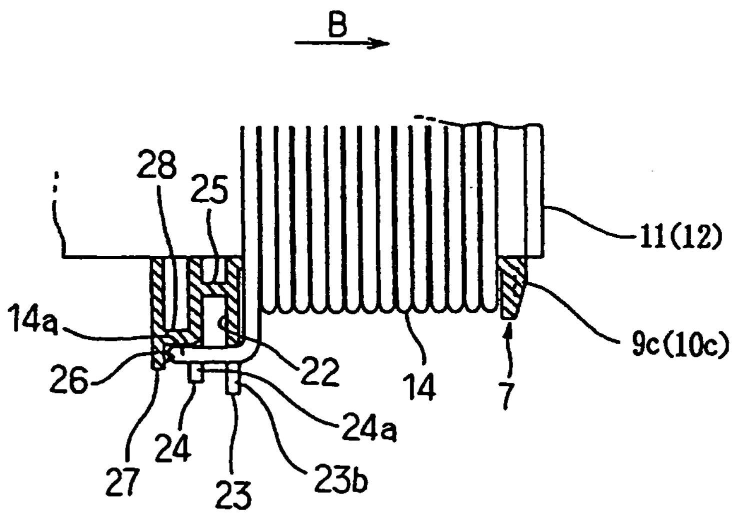

18
20
15a
19
19a
6
9a
9a
9b
9b
10b
A
11
12
11

FIG. 12


25
8
28
11(12)
26
13a
13
9c(10c)
23
7
27
24
22
23a
B

F I G. 1 3


B
28
25
11(12)
14a
9c(10c)
26
22
14
7
24a
24
27
23
23b

F I G. 1 4

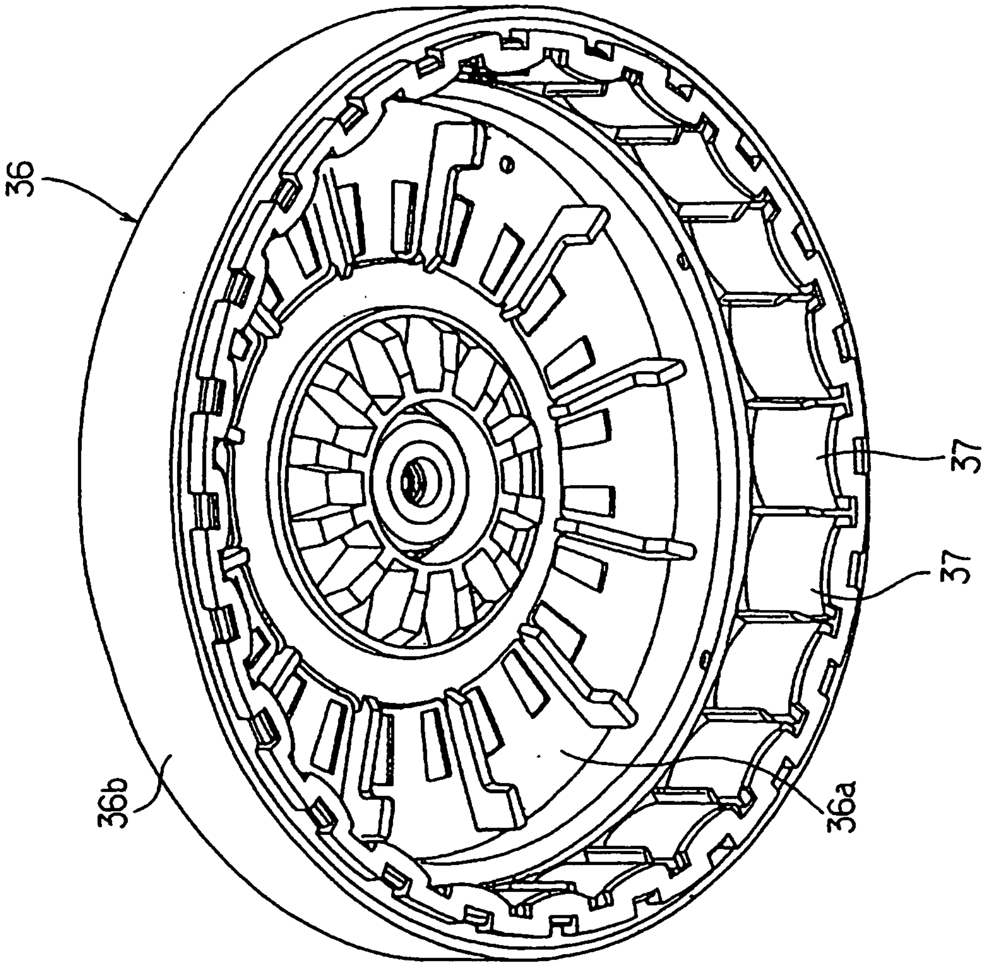


FIG. 15

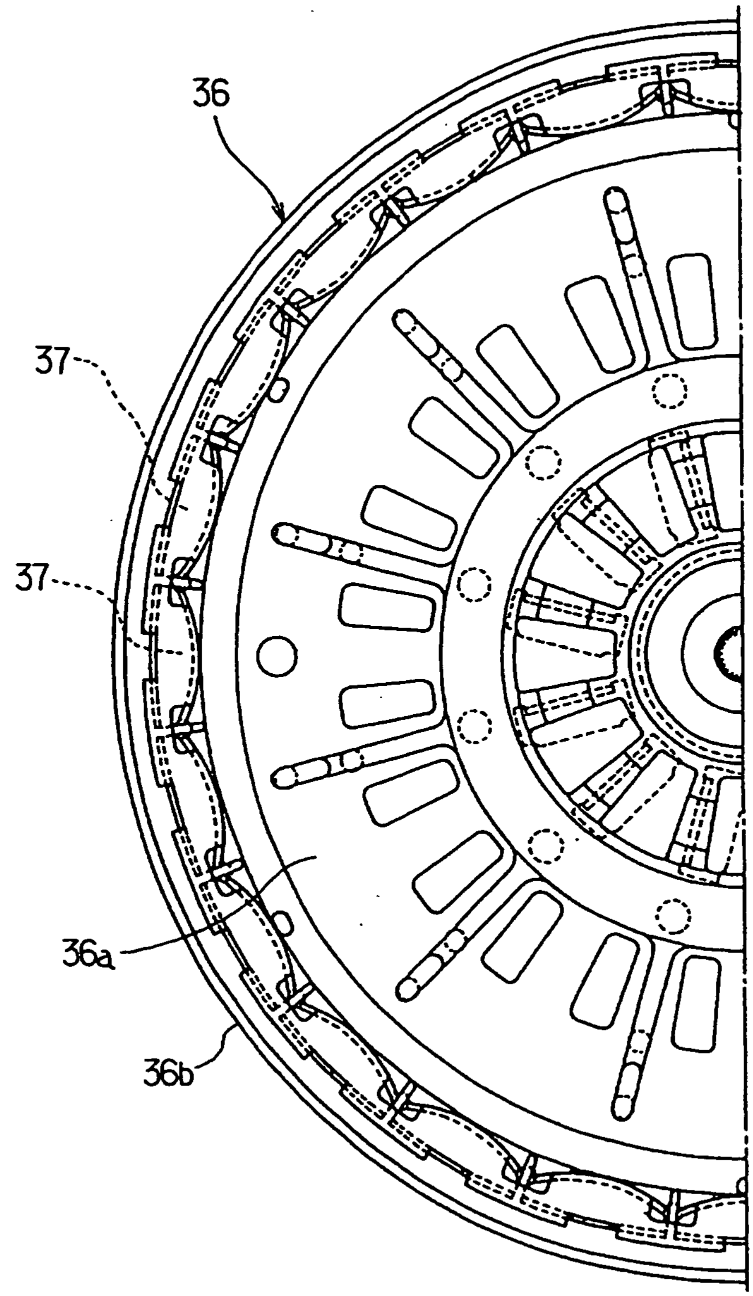
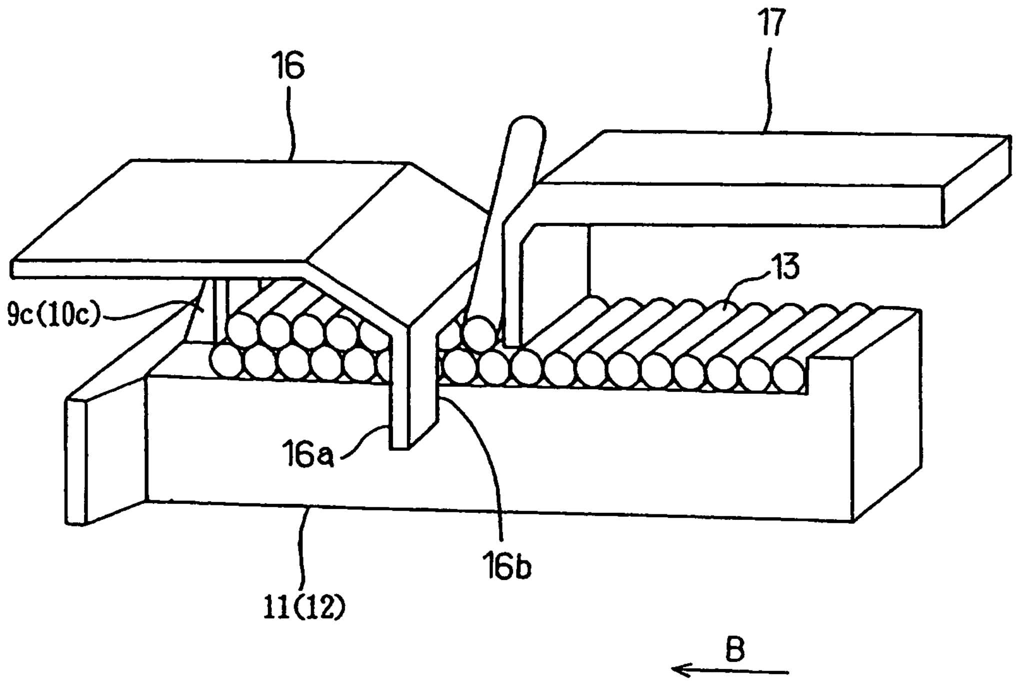


FIG. 16



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DIRECT-CURRENT MOTOR AND METHOD OF MAKING THE SAME

This invention relates to a direct-current motor having an armature including a yoke, a plurality of teeth integrally extending from the yoke in a circular disposition so as to define a plurality of slots, each tooth being provided with a coil wound thereon, and a method of making such a direct-current motor.

An armature for a conventional direct-current motor, for example, a stator for a three-phase brushless DC motor of the outer rotor type, has a stator core including a yoke and a number of teeth integrally extending from the yoke in a circular disposition so as to define a number of slots and provided with respective coils wound thereon. A distal end opening of each slot is half-closed so that each slot is formed into a semienclosed slot. Consequently, a variation of permeance between the stator core and a rotor in a direction of rotation of the rotor or in the circumferential direction is reduced such that a cogging torque which is substantially a torque variation can be reduced.

In another conventional DC motor, the teeth have two alternately different circumferential widths at the respective distal ends thereof. In this construction, the semienclosed slots have alternately different circumferential pitches at the centers of the openings thereof. The randomicity of the circumferential pitches reduces the variations in the permeance. This effectively reduces the cogging torque.

A primary object of the present invention is to provide a DC motor which has a core including a yoke and a plurality of teeth extending integrally from the yoke and in which the teeth include wide teeth and narrow teeth so that the cogging torque can be reduced, and a method of making the DC motor.

A second object of the invention is to provide a DC motor wherein a degree of tension exerted on a magnet wire wound on the teeth into coils can be rendered uniform among the coils such that the magnetic property and electric characteristics are uniformed among the phases and coils, and a method of making the DC motor.

The present invention provides a direct-current motor comprising a core including a yoke and a plurality of teeth extending integrally from the yoke in a circular disposition so as to define a plurality of slots, and coils wound on the respective teeth to form a plurality of phases, wherein the teeth include a plurality of types of teeth having different circumferential widths, wherein the coils of each phase are disposed so that the coil wound on the wide tooth is adjacent via the coil of another phase to the coil wound on the narrow teeth, and wherein the coils are wound on the teeth repeatedly alternately in a sequence of the wide tooth and the narrow tooth or in a reverse sequence.

According to the above-described motor, the teeth include the plurality of types of teeth having different circumferential widths. Consequently, the variations in permeance between the stator core and a rotor in the

circumferential direction is reduced such that the cogging torque can be reduced. Furthermore, the coils of each phase are wound on the teeth repeatedly alternately in the sequence of the wide tooth and the narrow tooth or in the reverse sequence. Consequently, since the lengths of the intercoil wires between the coils are uniformed, tension applied to a magnet wire during the winding of coils can be uniformed between the coils.

In a preferred form, each wide tooth and each narrow tooth have circumferential widths at ends thereof larger than circumferential widths of coil-winding sections thereof respectively, and the end width of each wide tooth is set to be larger than the end width of each narrow tooth. Since this construction results in no local magnetic saturation in each of the wide and narrow teeth, the magnetic properties are balanced between the teeth.

In another preferred form, the teeth include first and second teeth having circumferential widths differing from each other and circumferentially arranged alternately. The coils of each phase are disposed so that the coil wound on each first tooth is adjacent to the coil wound on each second tooth via the coil of the other or another phase therebetween. The coils of each phase are wound on the teeth repeatedly alternately in a sequence of the first tooth and the second tooth. As the result of the above-described disposition of the first and second teeth, the number of teeth and the tooth pitch are uniformed between the phases, the rotational characteristic of the motor can

be stabilized.

In further another preferred form, the number of phases of the coils is three, and intercoil wires between the coils belonging to one of the three phases are disposed at one of two end sides of the core with respect to a rotational axis of the motor. Intercoil wires between the coils belonging to each of the other phases are disposed at the other end side of the core. Since this construction distributes the intercoil wires at both sides of the core, the interphase withstand voltage can be prevented from being reduced due to the entanglement of the intercoil wires.

In further another preferred form, each coil has a beginning and a termination are disposed at a root side of the corresponding tooth. Locations where the respective intercoil wires are drawn out are not dispersed widely in the stator and the lengths of lead wires can be uniformed.

The invention also provides a method of making a direct-current motor which includes a core further including a yoke and a plurality of teeth extending integrally from the yoke in a circular disposition so as to define a plurality of slots, and coils wound on the respective teeth to form a plurality of phases, characterized by the steps of forming the plurality of teeth including a plurality of types of teeth having different circumferential widths, and winding a magnet wire on the teeth repeatedly alternately in a sequence of the wide tooth and the narrow tooth or in a reverse sequence, thereby forming the coils of each phase.

The invention will be described, merely by way of

example, with reference to the accompanying drawings, in which:

FIG. 1 is a plan view of the stator core employed in the DC motor of a first embodiment in accordance with the present invention;

FIG. 2 is an exploded perspective view of the stator core and an insulating end plate;

FIG. 3 is a perspective view of a distal end of the magnetic pole tooth;

FIG. 4 is a perspective view of the stator;

FIG. 5 is a longitudinal section of the tooth on which the coil is wound;

FIG. 6 is a perspective view of the tooth on which the coil including an additional coil is wound;

FIG. 7 is a partial top view of the stator, showing the phase U coils;

FIG. 8 is a partial top view of the stator, showing the phase V coils;

FIG. 9 is a partial top view of the stator, showing the phase W coils;

FIG. 10 is a partial enlarged top view of the insulating end plate;

FIG. 11 is a partial longitudinal section of the tooth and the coil wound thereon, showing accommodation of the intercoil wire of the phase W coil;

FIG. 12 is a partial perspective view of the stator, showing accommodation of the intercoil wire of the phase W coil;

FIG. 13 is a partial longitudinal section of the tooth and the coil wound thereon, showing accommodation of the intercoil wire of the phase U coil;

FIG. 14 is a partial longitudinal section of the tooth and the coil wound thereon, showing accommodation of the intercoil wire of the phase V coil;

FIG. 15 is a perspective view of the rotor;

FIG. 16 is a partial plan view of the rotor; and

FIG. 17 is a schematic perspective view of the formers of a winding machine.

One embodiment of the present invention will be described with reference to the drawings. In the embodiment, the invention is applied to a three-phase 24 pole 36 slot brushless DC motor of the outer rotor type for rotating a pulsator and a wash tub of a full automatic washing machine. Referring first to FIG. 4, a stator of the motor is shown. The stator includes a stator core 1 formed by stacking a plurality of steel sheets. The stator core 1 includes a generally cylindrical inner yoke 2, eighteen first teeth 3 radially extending from the inner yoke 1 and eighteen second teeth 4 radially extending from the inner yoke 2. The first and second teeth 3 and 4 are disposed alternately at an equal pitch (=10 degrees) circumferentially with respect to the stator.

Each of the first teeth 3 comprises a generally square coil-winding section 3a and a tooth end. The tooth end serves as a pole section 3b circumferentially projecting from both circumferential faces in the vicinity of the

distal end of the coil-winding section 3a. Each pole section 3b has a circumferential width (hereinafter, "width") set at W1b. The width W1b of each pole section 3b and a width W1a of each coil-winding section 3a are set as W1b>W1a under a predetermined ratio.

Each of the second teeth 4 comprises a generally square coil-winding section 4a and a tooth end a pole section 4b circumferentially projecting from both circumferential faces in the vicinity of the distal end of the coil-winding section 4a. Each pole section 4b has a circumferential width W2a set to be smaller than the width W1a of the coil-winding section 3a of each first tooth 3. The width W2b of each pole section 4b and the width W2a of each coil-winding section 4a are set as W2b>W2a under a ratio previously determined to prevent occurrence of partial magnetic saturation.

Slots 5 are defined by the first teeth 3 and the second teeth 4 respectively. Each slot 5 is formed into a semienclosed slot. The centers of slot openings 5a are shifted alternately in a direction of rotation of a rotor and in an opposite direction relative to the center line between the teeth 3 and 4.

The stator core 1 is covered with two insulating end plates 6 and 7 at both end sides thereof in the direction of axis of rotation of the rotor or at upper and lower sides thereof as viewed in FIG. 2, respectively. Each of the insulating end plates 6 and 7 is made from an insulating synthetic resin such polybutylene terephthalate containing

glass filler by injection molding. Each insulating end plate includes a ring-shaped portion 8, eighteen first slot insulating portions 9 radially extending from the ring-shaped portion 8, and eighteen second slot insulating portions 10 radially extending from the ring-shaped portion 8. The first and second slot insulating portions 9 and 10 of each insulating end plate are circumferentially disposed alternately at an equal pitch (=10 degrees).

Each first slot insulating portion 9 includes a tub-shaped first tooth cover 9a and a generally U-shaped first flange 9b located at a distal end of the first tooth cover 9a, as shown in FIG. 3. Each tooth cover 9a has an inner width approximately equal to the width W1a of the coil-winding section 3a. Each flange 9b has a width approximately equal to the width W1b of the pole section 3b.

Each second slot insulating portion 10 includes a second tooth cover 10a having a tub-shaped section and a generally U-shaped second flange 10b located at a distal end of the second tooth cover 10a. Each tooth cover 10a has an inner width approximately equal to the width W2a of the coil-winding section 4a. Each flange 10b has a width approximately equal to the width W2b of the pole section 4b.

The first slot insulating portions 9 of the insulating end plates 6 and 7 are abutted against each other axially centrally with respect to the stator core 1 as shown in FIG. 3. The second slot insulating portions 10 of the insulating end plates 6 and 7 are also abutted against each other axially centrally with respect to the stator core 1.

Inner faces of the tooth covers 9a and 10a closely contact with the outer faces of the coil-winding sections 3a and 4a. The outer faces of the coil-winding sections 3a are covered with the tooth covers 9a. The outer faces of the coil-winding sections 4a are covered with the tooth covers 10a. Outer peripheral faces of the flanges 9b and 10b closely contact with inner peripheral faces of the pole sections 3b and 4b.

Reference numeral 11 in FIG. 4 designates wide first insulated teeth including the first teeth 3 and the slot insulating portions 9 covering the first teeth 3 respectively. Reference numeral 12 designates narrow second insulated teeth including the second teeth 4 and the second slot insulating portions 10 covering the second teeth 4 respectively.

Phase U coils 13 are wound on the outer peripheries of the insulated teeth 11 and 12 corresponding to the phase U, namely, on the outer peripheries of the slot insulating portions 9 and 10 respectively. These phase U coils 13 are formed by winding a single magnet wire continuously on six insulated teeth 11 and six insulated teeth 12. In a winding sequence, as shown by reference symbol U in FIG. 1, the magnet wire is firstly wound on the wide first tooth 3. The magnet wire is secondly wound on the narrow second tooth 4 which is two teeth away from the firstly wound tooth 3 in the direction of arrow A in FIG. 1. Then, the magnet wire is thirdly wound on the wide first tooth 3 which is two teeth away from the secondly wound tooth 4 in the direction

of arrow A. The magnet wire is continuously wound on these teeth 3 and 4 without being cut off. Intercoil wires 13a of the phase U coils 13 are disposed at the axial underside of the stator core 1 as shown in FIG. 13.

Phase V coils 14 are wound on the outer peripheries of the insulated teeth 11 and 12 corresponding to the phase V, namely, on the outer peripheries of the slot insulating portions 9 and 10 respectively, as shown in FIG. 4. These phase U coils 14 are formed by winding a single magnet wire continuously on six insulated teeth 11 and six insulated teeth 12. In a winding sequence, as shown by reference symbol V in FIG. 1, the magnet wire is firstly wound on the wide first tooth 3. The magnet wire is secondly wound on the narrow second tooth 4 which is two teeth away from the firstly wound tooth 3 in the direction of arrow A in FIG. 1. Then, the magnet wire is thirdly wound on the wide first tooth 3 which is two teeth away from the secondly wound tooth 4 in the direction of arrow A. The magnet wire is continuously wound on these teeth 3 and 4 without being cut off. Intercoil wires 14a of the phase V coils 14 are disposed at the axial underside of the stator core 1 as shown in FIG. 14.

Phase W coils 15 are wound on the outer peripheries of the insulated teeth 11 and 12 corresponding to the phase W, namely, on the outer peripheries of the slot insulating portions 9 and 10 respectively, as shown in FIG. 4. These phase U coils 15 are formed by winding a single magnet wire continuously on six insulated teeth 11 and six insulated

teeth 12. In a winding sequence, as shown by reference symbol W in FIG. 1, the magnet wire is firstly wound on the wide first tooth 3. The magnet wire is secondly wound on the narrow second tooth 4 which is two teeth away from the firstly wound tooth 3 in the direction of arrow A in FIG. 1. Then, the magnet wire is thirdly wound on the wide first tooth 3 which is two teeth away from the secondly wound tooth 4 in the direction of arrow A. The magnet wire is continuously wound on these teeth 3 and 4 without being cut off. Intercoil wires 15a of the phase W coils 15 are disposed at the upper face side of the stator core 1 as shown in FIG. 11. Thus, the intercoil wires 15a of the phase W coils 15 are disposed at the side opposite the intercoil wires 13a and 14a of the phase U and V coils 13 and 14.

In each of the coils 13 to 15, the magnet wire is wound alternately from the root side to the distal end side of the tooth and from the distal end side to the root side for every one layer, so that each coil is formed into a four-layer regular winding having a generally trapezoidal shape in cross section. The beginning and termination of each of the coils 13 to 15 are located at the root side of each of the insulated teeth 11 and 12. Numerals assigned to the wound coil turns in FIG. 5 designate the winding sequence. The number of turns of the coils 13 to 15 per turn is decreased one as each coil is wound to the upper layers.

Additional coils 13b, 14b and 15b and 13c, 14c and 15c are further wound on the respective wide first insulated

teeth 11 as shown in FIG. 6. The additional coils 13b to 15b and 13c to 15c are located at radially opposite ends of the respective coils 13 to 15. The additional coils 13b to 15b and 13c to 15c are wound successively from the winding of the coils 13 to 15 so as to fill up spaces at opposite ends of the coils, respectively. The final layers of the coils 13 to 15 and final layers of the additional coils 13b to 15b and 13c to 15c are set so as to be approximately at the same axial height.

The flanges 9b and 10b of the slot insulating portions 9 and 10 have integrally formed protrusions 9c and 10c respectively. The protrusions 9c and 10c are eliminated for clarity in FIG. 2. Each of the protrusions 9c and 10c has approximately the same axial height as each of the coils 13 to 15. The protrusions 9c and 10c prevent the coils 13 to 15, the auxiliary coils 13b to 15b and 13c to 15c from sliding down toward the distal end sides of the teeth 3 and 4.

The slot insulating portions 9 and 10 have a plurality of guide grooves 9d and 10d located at circumferential both ridges of the tooth covers 9a and 10a respectively as shown in FIG. 3. Each of the guide grooves 9d and 10d has approximately the same width as the diameter R (=0.6 mm) of the magnet wire and a depth set approximately at one half of the diameter R of the magnet wire. The turns of the magnet wire constituting the lower most layers of the respective coils 13 to 15 are accommodated in the guide grooves 9d and 10d.

The coils 13 to 15 and the additional coils are wound on the insulated teeth 11 and 12 by rotating a head of an automatic winding machine (not shown). A pair of formers 16 and 17 each formed into a generally L-shaped plate as well known in the art are mounted on the winding machine to be moved together, as shown in FIG. 17. The former 16 has a pair of protrusions 16a defining an escape groove 16b therebetween. In the winding of the coils 13 to 15 and the additional coils 13b to 15b and 13c to 15c, the escape groove 16b of the former 16 is fitted with the outside of each of the insulated teeth 11 and 12, and the formers 16 and 17 are intermittently moved at the pitch R in the direction of length of each tooth or in the direction of arrow B and in the direction opposite the arrow B so that the magnet wire is guided along distal ends of the formers 16 and 17.

The upper insulating end plate 6 is formed with a ring-shaped groove 18 as shown in FIGS. 4, 11 and 12. The groove 18 is defined by ring-shaped portions 19, 20 and an annular bottom plate 21. The outer ring-shaped portion 19 has notches 19a formed in an outer wall thereof to correspond to the phase W coils 15 respectively. Each of the intercoil wires 15a of the phase W coils 15 is inserted through the respective notch 15a into the groove 18, being further drawn through the other notch 15a out of the groove 18, as shown in FIG. 12. The ring-shaped portions 19 and 20 and the bottom plate 21 are formed integrally with the insulating end plate 6.

The lower insulating end plate 7 is formed with a ring-shaped groove 22 as shown in FIG. 13. The groove 22 is defined by ring-shaped portions 23, 24 and an annular bottom plate 25. The outer ring-shaped portion 23 has notches 23a formed in an outer wall thereof to correspond to the phase U coils 22 respectively. Each of the intercoil wires 13a of the phase U coils 13 is inserted through the respective notch 23a into the groove 22, being further drawn through the other notch 23a out of the groove 22, as shown in FIG. 12.

The lower insulating end plate 7 is formed with a ring-shaped groove 26 located radially inside the groove 22 as shown in FIG. 14. The groove 26 is defined by two ring-shaped portions 24 and 27 and an annular bottom plate 28. The ring-shaped portions 23 and 24 are formed with a pair of notches 23a and 24a corresponding to each phase V coil 14. Each of the intercoil wires 14a of the phase V coils 14 is inserted through the respective notches 23b and 24a into the groove 26, being further drawn through the other notches 23b and 24a out of the groove 26. The ring-shaped portions 23, 24 and 27 and the bottom plates 25 and 18 are formed integrally with the insulating end plate 7.

The bottom plate 21 of the upper insulating end plate 6 has integrally formed rectangular cylindrical terminal insertion portions 29 to 31 as shown in FIG. 10. Each of the terminal insertion portions 29 to 31 has inner and outer peripheral walls formed with generally U-shaped small grooves 32. The first of the twelve phase U coils 13 is

wound on the wide first insulated tooth 11 located in the vicinity of the terminal insertion section 29. The beginning 13s of the twelve serially connected phase U coils 13 is inserted in the both small grooves 32 of the terminal insertion portion 29.

The first of the twelve phase V coils 14 is wound on the narrow first insulated tooth 12 located in the vicinity of the terminal insertion section 30 as shown in FIG. 8. The beginning 14s of the twelve serially connected phase V coils 14 is inserted in the both small grooves 32 of the terminal insertion portion 30. The first of the twelve phase W coils 15 is wound on the narrow second insulated tooth 12 located in the vicinity of the terminal insertion portion 31, as shown in FIG. 9. The beginning 15s of the twelve phase W coils 15 is inserted in both small grooves 32 of the terminal insertion portion 31.

The bottom plate 21 of the upper insulating end plate 6 has integrally formed rectangular cylindrical terminal insertion portions 33 to 35 as shown in FIG. 10. Each of the terminal insertion portions 29 to 31 has inner and outer peripheral walls formed with generally U-shaped small grooves 32. The twelfth of the twelve phase U coils 13 is wound on the narrow second insulated tooth 12 located in the vicinity of the terminal insertion section 33, as shown in FIG. 7. The termination 13e of the twelve serially connected phase U coils 13 is inserted in the both small grooves 32 of the terminal insertion portion 33.

The twelfth of the twelve phase V coils 14 is wound on

the wide first insulated tooth 11 located in the vicinity of the terminal insertion section 34 as shown in FIG. 8. The termination 14e of the twelve serially connected phase V coils 14 is inserted in the both small grooves 32 of the terminal insertion portion 34. The twelfth of the twelve phase W coils 15 is wound on the wide first insulated tooth 12 located in the vicinity of the terminal insertion portion 31, as shown in FIG. 9. The termination 15e of the twelve phase W coils 15 is inserted in both small grooves 32 of the terminal insertion portion 35.

Common connecting terminals (not shown) are inserted in the terminal insertion portions 29 to 31 respectively. External connecting terminals (not shown) are inserted in the terminal insertion portions 33 to 35 respectively. Each of these terminals breaks through a sheath of the magnet wire during the step of insertion to thereby come into contact with the conductors. A terminal block (not shown) made from a synthetic resin is mounted on the upper insulating end plate 6. The common connecting terminals are connected via a conductive plate embedded in the terminal block in common with each other. The external connecting terminals are connected via a conductive plate embedded in the terminal block to a power supply (not shown). Thus, the phase coils 13 to 15 are connected in a three-phase configuration to the power supply.

A rotor 36 is disposed to be outside the stator core 1. The rotor 36 comprises a dish-shaped metal frame 36a with a closed upper end, a ring member 36b made from a synthetic

resin and extending along an outer circumferential face of an opening of the frame 36a, twenty-four rotor magnets 37 disposed along an inner circumferential face of the opening of the frame 36a. The frame 36a, ring member 36b and rotor magnets 37 are integrated by a resin. An output shaft (not shown) is connected to a central portion of the rotor 36. Inner peripheral faces of the rotor magnets 37 are opposed to the outer peripheral faces of the pole sections 3b of the first teeth 3 and the pole sections 4b of the second teeth 4 with a predetermined gap therebetween. The rotor magnets correspond to the pole sections.

A manner of winding the coils 13 to 15 will now be described. The insulating end plates 6 and 7 are put onto the stator core 1 from axial both sides. Thereafter, as shown in FIG. 7, the beginning 13s of the magnet wire is inserted into both small grooves 32 of the terminal insertion section 29. The common connecting terminal is pushed into the terminal insertion section 29 so that the beginning 13s is fixed by the common connecting terminal. Upon rotation of the head of the winding machine in the above-described condition, the magnet wire is wound on the wide first insulated tooth 11 located in the vicinity of the terminal insertion section 29.

The formers 16 and 17 are intermittently moved at the pitch R repeatedly alternately from the root of the insulated tooth 11 toward the distal end side of the tooth or in the direction of arrow B and from the distal end side toward the root side of the tooth 11 or in the direction

opposite arrow B so that the magnet wire is caused to fall into the guide groove 9d, as shown in FIG. 17. Thus, the magnet wire is wound to form a first layer of the phase U coil 13.

Upon completion of the winding for the first layer of the phase U coil 13, the formers 16 and 17 are moved in the direction opposite the arrow B and then in the direction of arrow B so that the magnet wire of the upper layer is caused to fall between the turns of the magnet wire of the lower layer. The second, third and fourth layers of the phase U coil 13 are sequentially wound.

When the phase U coil 13 has been wound on the wide first insulated tooth 11, the intercoil wire 13a of the phase U coil 13 is inserted through the notch 23a into the groove 22, being drawn through another notch 23a out of the groove 22. Thereafter, the magnet wire is wound on the narrow second insulated tooth 12 which is two teeth away from the previously wound tooth 11 in the direction of arrow A, in the same manner as described above.

When the phase U coil 13 has been wound on the narrow second insulated tooth 11, the intercoil wire 13a of the phase U coil 13 is inserted through the notch 23a into the groove 22. The phase U coils 13 are sequentially wound on the wide first insulated tooth 11 two teeth away from the previously wound tooth 11 in the direction of arrow A and the narrow second insulated tooth 11 two teeth away from the previously wound tooth 11. Finally, the phase U coil 13 is wound on the narrow second insulated tooth 11 two teeth away

from the firstly wound tooth 11 in the direction opposite to arrow A, as shown in FIG. 7. Thereafter, the termination 13e of the phase U coils 13 is inserted into the small grooves 32 of the terminal insertion section 33, and the external connecting terminal is pushed into the terminal insertion portion 33 so that the termination 13e is brought into electrical contact with the external connecting terminal and also fixed.

When the twelve phase U coils 13 have been wound on the insulated teeth 11 and 12, the beginning 14s of the magnet wire is inserted into the small grooves 32 of the terminal insertion portion 30, and the common connecting terminal is pushed into the terminal insertion portion 30 so that the beginning 14s is brought into electrical contact with the common connecting terminal and also fixed, as shown in FIG. 8. The head of the winding machine is then rotated so that the magnet wire is wound on the narrow second insulated tooth 12 adjacent to the wide first insulated tooth 11 on which the first phase U coil 13 has been wound, in the direction opposite to arrow A, whereby the phase V coil 14 is wound.

The formers 16 and 17 are moved repeatedly alternately from the tooth root side toward the tooth distal end side and from the tooth distal end side to the tooth root side, so that the phase V coil 14 is wound in the same manner as the phase U coils 13. Thus, the direction of movement of the formers 16 and 17 is reversed for every one layer. When the phase V coil 14 has been wound on the narrow second

insulated tooth 12, the intercoil wire 14a of the phase V coil 14 is inserted through the pair of notches 23b and 24a into the groove 26. The intercoil wire 14a is then drawn through another pair of notches 24a and 23b out of the groove 26. Thereafter, another phase V coil 14 is wound on the wide first insulated tooth 11 two teeth away from the previously wound narrow tooth 12 in the direction of arrow A.

When the phase V coil 14 has been wound on the wide first insulated tooth 11, the phase V coils 14 are sequentially wound on the narrow second insulated tooth 12 two teeth away from the previously wound tooth 11 in the direction of arrow A and the wide first insulated tooth 11 two teeth away from the previously wound tooth 12. Finally, the phase V coil 14 is wound on the wide first insulated tooth 11 two teeth away from the firstly wound tooth 12 in the direction opposite to arrow A, as shown in FIG. 8. Thereafter, the termination 14e of the phase V coils 14 is inserted into the small grooves 32 of the terminal insertion portion 34, and the external connecting terminal is pushed into the terminal insertion portion 34 so that the termination 14e is brought into electrical contact with the external connecting terminal and also fixed.

When the twelve phase V coils 14 have been wound on the insulated teeth 11 and 12, the beginning 15s of the magnet wire is inserted into the small grooves 32 of the terminal insertion portion 31, and the common connecting terminal is pushed into the terminal insertion portion 31 so that the

beginning 15s is brought into electrical contact with the common connecting terminal and also fixed. The head of the winding machine is then rotated so that the magnet wire is wound on the narrow second insulated tooth 12 adjacent to the wide first insulated tooth 11 on which the first phase U coil 13 has been wound, in the direction of arrow A, whereby the phase W coil 15 is wound.

The formers 16 and 17 are moved repeatedly alternately from the tooth root side toward the tooth distal end side and from the tooth distal end side to the tooth root side, so that the phase W coil 15 is wound in the same manner as the phase U and V coils 13 and 14. Thus, the direction of movement of the formers 16 and 17 is reversed for every one layer. When the phase W coil 15 has been wound on the narrow second insulated tooth 12, the intercoil wire 15a of the phase W coil 15 is inserted through the notch 19b into the groove 18 as shown in FIG. 11. The intercoil wire 15a is then drawn through the notch 19a at the subsequent location. Thereafter, another phase V coil 14 is wound on the wide first insulated tooth 11 two teeth away from the previously wound narrow tooth 12 in the direction of arrow A.

When the phase W coil 15 has been wound on the wide first insulated tooth 11, the phase W coils 15 are sequentially wound on the narrow second insulated tooth 12 two teeth away from the previously wound tooth 11 in the direction of arrow A and the wide first insulated tooth 11 two teeth away from the previously wound tooth 12. Finally,

the phase V coil 14 is wound on the wide first insulated tooth 11 two teeth away from the firstly wound tooth 12 in the direction opposite to arrow A, as shown in FIG. 9. Thereafter, the termination 15e of the phase W coils 15 is inserted into the small grooves 32 of the terminal insertion portion 35, and the external connecting terminal is pushed into the terminal insertion portion 35 so that the termination 15e is brought into electrical contact with the external connecting terminal and also fixed.

After the coils 13 to 15 have been wound on the wide first insulated teeth 11 respectively, the formers 16 and 17 are moved alternately to the tooth distal end side of the coil 13 and to the tooth root side so that the magnet wire is caused to fall to the tooth distal end side and the tooth root side. As a result, the additional coils 13b to 15b are formed at the tooth distal end side, and the additional coils 13c to 15c are formed at the tooth root side. The terminations of the additional coils 13c to 15c are drawn to the tooth root side.

According to the foregoing embodiment, the width W1b of the pole sections 3b of the first teeth 3 differs from the width W2b of the pole sections 4b of the second teeth 4. Accordingly, the openings 5a of the slots 5 are displaced alternately in the direction of rotation of the rotor and the direction opposite the rotation direction, namely, in the direction of arrow A and the direction opposite arrow A relative to the centers of the teeth 3 and 4. Consequently, since the variations in the permeance between the rotor 36

and the stator core are reduced, the cogging torque can effectively be reduced.

In each phase, the magnet wire is first wound on the wide first tooth 3 and then on the narrow second tooth 4. The magnet wire is thus wound repeatedly alternately on the teeth 3 and 4 having the different widths. Accordingly, the lengths of the intercoil wires 13a, 14a and 15a are uniformed even when the teeth 3 and 4 have different widths. Since this results in equalization of the tension exerted to each of the phase coils 13 to 15 during the winding, the coils 13 to 15 are wound in the balanced relation with respect to the weight and configuration. Consequently, since variations in an amount of extension of the magnet wire are reduced among the coils 13 to 15, the resistance values of the coils 13 to 15 can be stabilized and the differences in the performance of the coils 13 to 15 can be reduced. With this effect, the total interphase length of the intercoil wires 13a, 14a and 15a is uniformed. Consequently, the variations in the amount of extension of the magnet wire in each phase can be reduced and the differences in the interphase electric performance can be reduced.

The wide first teeth 3 and the narrow second teeth 4 are disposed alternately. As a result, the numbers of the first and second teeth are uniformed among the phases, or the disposition angles of the first and second teeth are uniformed among the phases. Consequently, the motor torque can be stabilized.

The width W1b of the pole section 3b of each first tooth 3 is larger than the width W2b of the pole section 4b of each second tooth 4. The width W1a of each coil-winding section 3a is larger than the width W2a of each coil-winding section 4a. Accordingly, the magnetic flux density is balanced between the pole sections 3b and the coil-winding sections 3a, between the pole sections 4b and the coil-winding sections 4a, and between the wide teeth 3 and the narrow teeth 4. Consequently, since a partial magnetic saturation is prevented, the cogging torque can be reduced further effectively.

In the phase coils 13 to 15, the magnet wire is wound in a sequence of the wide first tooth 3 and the narrow second tooth 4 two teeth away from the previously wound wide first tooth 3. Accordingly, the lengths of the intercoil wires 13a to 15a and the total length of the intercoil wires in each phase are each rendered minimum and uniformed. Consequently, since the intercoil wires 13a to 15a are prevented from being entangled, the withstand voltage can be improved between the coils belonging to different phases.

The phase W intercoil wires 15a are disposed at the axial upper face side of the stator core 1, and the phase U and V intercoil wires 13a and 14a are disposed at the axial underside of the stator core 1. Consequently, since the intercoil wires 13a to 15a are prevented from being entangled more reliably, the withstand voltage can further be improved between the coils belonging to different phases.

The beginnings and terminations of the phase coils 13

to 15 are drawn to the tooth root side. Since the locations where the intercoil wires 13a to 15a are drawn are concentrated on the tooth root side of the stator core 1, the lengths of the intercoil wires 13a to 15a and the total length of the intercoil wires 13a to 15a in each phase can further be uniformed among the phases. Furthermore, the number of teeth in each phase is set at 12 which is an even number. Consequently, the total length of the intercoil wire in each phase can further be uniformed among the phases. This effect cannot be achieved when the total number of teeth in each phase is set at an odd number.

Each of the teeth 3 and 4 has the end having the larger width than the other portion thereof. By making an effective use of this arrangement, the additional coils 13b to 15b and 13c to 15c are wound on the first insulated teeth. The dead space is thus used effectively and accordingly, the number of turns can be increased. Moreover, the motor output can be fine controlled by changing the number of turns of each of the additional coils.

Each of the coils 13 to 15 is wound into four layers in the foregoing embodiment. However, each coil may be wound into one to three layers or five or more layers. The beginning and termination of each coil can be positioned at the inner yoke 2 side when the number of layers in each phase is set at an even number. This is advantageous in uniforming the length of the intercoil wires among the phases.

Each of the coils 13 to 15 is wound into a regular or normal winding in the foregoing embodiment. However, each coil may be wound into a random coil, instead. Furthermore, each of the coils 13 to 15 excluding the additional coils has such a configuration that the diameter at each of the lengthwise ends thereof with respect to the tooth is smaller than that of the other portion. However, the diameter of only one end may be smaller that that of the other portion, instead.

The total number of teeth of the stator core 1 is set at 36 in the foregoing embodiment. The number may be set at any value provided that the number of teeth per phase is at or above 2. In particular, the pole of each phase is preferably set at an even number.

The intercoil wires 13a and 14a of the phases U and V are disposed at the lower side of the stator core 1, whereas the intercoil wires 15a of the phase W are disposed at the upper side of the stator core. For example, the intercoil wires 13a and 15a of the phases U and W may be disposed at the upper side of the stator core, and the intercoil wires 14a of the phase V may be disposed at the lower side of the stator core 1, instead. In other words, the intercoil wires of two phases may be disposed at axial one end side of the stator core 1, and the intercoil wires of the other phase may be disposed at the axial other end of the stator core 1, instead.

Although the additional coils 13b to 15b and 13c to 15c are wound on the first insulated teeth in the foregoing

embodiment, the additional coils may or may not be provided. Furthermore, the coils 13 to 15 are wound on the insulating end plates 6 and 7 attached to the stator core 1. For example, however, the surface of the stator core 1 may be covered with an insulating resin layer such as a plastic layer by the insert molding, and the coils 13 to 15 may be wound on the insulating resin layers, instead. Furthermore, the insulating end plates 6 and 7 may be eliminated, and a sufficiently insulated magnet wire may be wound directly on the teeth 3 and 4 to form the coils 13 to 15.

Two types of teeth 3 and 4 having the pole sections 3b and 4b with different widths respectively are employed in the foregoing embodiment. However, three or more types of teeth having pole sections with different widths respectively may be used, instead. For example, in a three-phase nine-pole motor employing three types of teeth having pole sections with three different widths respectively, the magnetic wire is wound on the teeth repeatedly in a sequence of the tooth with a wide pole section, the tooth with a pole section of middle width, and the tooth with a narrow pole section. Alternatively, the magnetic wire is wound on the teeth repeatedly in a sequence of the tooth with a narrow pole section, the tooth with a pole section of middle width, and the tooth with a wide pole section. The width of the pole section of middle width is relatively smaller than the width of the wide pole section and larger than the width of the narrow pole section. In this arrangement, the cogging torque can be reduced to a large extent with the increase in

the number of types of teeth having the pole sections with different widths respectively. Furthermore, the above-described arrangement also ensures the uniformity in the length of the intercoil wires among the phases and the uniformity in the tension exerted on the magnet wire among the phases.

The first and second teeth 3 and 4 include the first and second pole sections 3b and 4b protruding from the distal ends thereof respectively in the foregoing embodiment. However, each tooth may be formed into the shape of a square bar having the same width from its root to its distal end, instead.

The width W1a of the coil-winding section 3a of each first tooth 3 differs from the width W2a of the coil-winding section 4a of each second tooth 4 in the foregoing embodiment. However, the widths W1a and W2a may be approximately the same, instead.

The invention is applied to the stator for the brushless DC motor of the outer rotor type in the foregoing embodiment. However, the invention may be applied to stators for brushless DC motors of the inner rotor type, stators for DC motors of the outer rotor type with respective brushes, stators for DC motors of the inner rotor type with respective brushes, rotors for DC motors of the outer rotor type with respective brushes, and rotors for DC motors of the inner rotor type with respective brushes. In other words, the invention may be applied to armatures for DC motors.

The foregoing description and drawings are merely illustrative of the principles of the present invention and are not to be construed in a limiting sense. Various changes and modifications will become apparent to those of ordinary skill in the art. All such changes and modifications are seen to fall within the scope of the invention as defined by the appended claims.

WE CLAIM:

1. A direct-current motor comprising:

a core including a yoke and a plurality of teeth extending integrally from the yoke in a circular disposition so as to define a plurality of slots; and

coils wound on the respective teeth to form a plurality of phases;

wherein the teeth include a plurality of types of teeth having different circumferential widths;

wherein the coils of each phase are disposed so that the coil wound on the wide tooth is adjacent via the coil of another phase to the coil wound on the narrow teeth; and

wherein the coils are wound on the teeth repeatedly alternately in a sequence of the wide tooth and the narrow tooth or in a reverse sequence.

2. A motor of claim 1, wherein each wide tooth and each narrow tooth have circumferential widths at ends thereof larger than circumferential widths of coil-winding sections thereof respectively, and the end width of each wide tooth is set to be larger than the end width of each narrow tooth.

3. A motor of claim 1, wherein each wide tooth and each narrow tooth have circumferential widths at ends thereof larger than circumferential widths of coil-winding sections thereof respectively, and each wide tooth has the circumferential widths of the tooth end and the coil-winding

section larger than each narrow tooth respectively.

4. A motor of claim 1, wherein the number of phases of the coils is three, wherein intercoil wires between the coils belonging to one of the three phases are disposed at one of two end sides of the core with respect to a rotational axis of the motor, and wherein intercoil wires between the coils belonging to each of the other phases are disposed at the other end side of the core.

5. A motor of claim 1, wherein each coil has a beginning and a termination are disposed at a root side of the corresponding tooth.

6. A direct-current motor comprising:

a core including a yoke and a plurality of teeth extending integrally from the yoke in a circular disposition so as to define a plurality of slots; and

coils wound on the respective teeth to form a plurality of phases;

wherein the teeth include first and second teeth having circumferential widths differing from each other and circumferentially arranged alternately;

wherein the coils of each phase are disposed so that the coil wound on each first tooth is adjacent to the coil wound on each second tooth via the coil of the other or another phase therebetween; and

wherein the coils of each phase are wound on the teeth

repeatedly alternately in a sequence of the first tooth and the second tooth.

7. A motor of claim 6, wherein each first tooth and each second tooth have tooth ends with circumferential widths larger than circumferential widths of coil-winding sections thereof respectively, and the tooth end width of each first tooth is set to be larger than the end width of each second tooth.

8. A motor of claim 6, wherein each first tooth and each second tooth have tooth ends with circumferential widths larger than circumferential widths of coil-winding sections thereof respectively, and each first tooth has the circumferential widths of the tooth end and the coil-winding section larger than each second tooth respectively.

9. A motor of claim 6, wherein the number of phases of the coils is three, and the coils of each phase are disposed so that between the coil of each first tooth and the coil of each second tooth in one phase, the coil of each first tooth and the coil of each second tooth in each of the other phases are disposed.

10. A motor of claim 6, wherein each coil has a beginning and a termination are disposed at a root side of the corresponding tooth.

11. A direct-current motor comprising:

a stator including a core further including a yoke and a plurality of teeth extending integrally from an outer circumferential side of the yoke in a circular disposition so as to define a plurality of slots, and coils of a plurality of phases wound the respective teeth of the core; and

a rotor including a plurality of permanent magnets disposed at an outer circumferential side of the stator;

wherein the teeth include first and second teeth having circumferential widths differing from each other and circumferentially arranged alternately;

wherein the coils of each phase are disposed so that the coil wound on each first tooth is adjacent to the coil wound on each second tooth via the coil of the other or another phase therebetween; and

wherein the coils of each phase are wound on the teeth repeatedly alternately in a sequence of the first tooth and the second tooth.

12. A method of making a direct-current motor which includes a core further including a yoke and a plurality of teeth extending integrally from the yoke in a circular disposition so as to define a plurality of slots, and coils wound on the respective teeth to form a plurality of phases, the method comprising the steps of:

forming the plurality of teeth including a plurality of types of teeth having different circumferential widths; and

winding a magnet wire on the teeth repeatedly alternately in a sequence of the wide tooth and the narrow tooth or in a reverse sequence, thereby forming the coils of each phase.

13. A direct-current motor substantially as herein described with reference to the accompanying drawings.

14. A method of making a direct-current motor substantially as herein described with reference to the accompanying drawings.

The Patent Office

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Claims searched:	1-14	**Date of search:**	29 September 1998

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H2A [AKC4A, AKC4, AKE2, AKR1, AKR5, AKR6, AKR7, AKR8, AKF1A, AKF1, AKH1, AKH2]

Int Cl (Ed.6): H02K [01/08, 01/14, 01/16, 01/24, 01/26, 03/28, 23/42, 29/03]

Other:

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	NONE	

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